

Anomalies in experimental data for the EPR-Bohm experiment: Are both classical and quantum mechanics wrong?

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Abstract

We analyze anomalies in data to test the violation of Bell's inequality for the EPR-Bohm experiment. We found that the experimental correlations for photon polarization have an intriguing property. In the experimental data there are visible non-negligible deviations of probabilities $P_{++}^{\text{exp}}(\alpha, \beta)$, $P_{+-}^{\text{exp}}(\alpha, \beta)$, $P_{-+}^{\text{exp}}(\alpha, \beta)$, $P_{--}^{\text{exp}}(\alpha, \beta)$ from the predictions of quantum mechanics, namely, $P_{++}(\alpha, \beta) = P_{--}(\alpha, \beta) = \frac{1}{2} \cos^2(\alpha - \beta)$ and $P_{+-} = P_{-+}(\alpha, \beta) = \frac{1}{2} \sin^2(\alpha - \beta)$. However, in some mysterious way those deviations compensate each other and finally the correlation $E^{\text{exp}}(\alpha, \beta) = P_{++}^{\text{exp}}(\alpha, \beta) - P_{+-}^{\text{exp}}(\alpha, \beta) - P_{-+}^{\text{exp}}(\alpha, \beta) + P_{--}^{\text{exp}}(\alpha, \beta)$ is in the complete agreement with the QM-prediction, namely, $E(\alpha, \beta) = P_{++}(\alpha, \beta) - P_{+-}(\alpha, \beta) - P_{-+}(\alpha, \beta) + P_{--}(\alpha, \beta) = \cos 2(\alpha - \beta)$. Therefore such anomalies play no role in the Bell's inequality framework. Nevertheless, other linear combinations of experimental probabilities do not have such a compensation property. There can be found non-negligible deviations from predictions of quantum mechanics. Thus neither classical nor quantum model can pass the whole family of statistical tests given by all possible linear combinations of the EPR-Bohm probabilities. Does it mean that both models are wrong?

1 Introduction

In this note we continue the discussion [1], [2] on anomalies in statistical data obtained in the experimental test [3] that showed the violation of Bells inequality [4] and closed the locality loophole. These anomalies were discovered in [1], [2], cf. also with anomalies discussed in the PhD-thesis of Alain Aspect [5]. We found that, although the experimental data really confirm the QM-prediction for correlations:

$$E(\alpha, \beta) = P_{++}(\alpha, \beta) - P_{+-}(\alpha, \beta) - P_{-+}(\alpha, \beta) + P_{--}(\alpha, \beta), \quad (1)$$

the QM-predictions can be violated for other linear combinations of experimental probabilities which are different from $E(\alpha, \beta)$.

This discovery of mentioned anomalies has extremely important consequences for the whole Bell's program of confronting classical and quantum models through the statistical test based on correlations. New advanced experiments should be performed to make a conclusion on applicability of Bell's scheme.

2 Anomalies: What is special in correlations?

We have seen [1], [2] that the correlation is a very special linear combination of probabilities which is surprisingly stable with respect to deviations of its summands from the QM-predictions. Although the experimental data can show deviations from QM for summands in the expression (1), these deviations *compensate each other* in the linear combination (1). Finally, (in spite of mentioned deviations for terms) the experimental correlation

$$E^{\text{exp}}(\alpha, \beta) = P_{++}^{\text{exp}}(\alpha, \beta) - P_{+-}^{\text{exp}}(\alpha, \beta) - P_{-+}^{\text{exp}}(\alpha, \beta) + P_{--}^{\text{exp}}(\alpha, \beta)$$

is in the agreement with predictions of QM. Hence, for some angles, the Bell's inequality is violated and the classical probabilistic model which was proposed by J. Bell to confront QM should be rejected.

In contrast to many papers, see, e.g., a number of papers in [6], we do not worry about rejection of the classical model for the EPR-Bohm experiment that was used by J. Bell. We *agree that it should be*

rejected.¹ We worry that, as it was pointed out in introduction, other linear combinations of probabilities do not exhibit such a deviation-compensation property.

One might think that any linear combination

$$E_c(\alpha, \beta) =$$

$$c_{++}P_{++}(\alpha, \beta) + c_{+-}P_{+-}(\alpha, \beta) + c_{-+}P_{-+}(\alpha, \beta) + c_{--}P_{--}(\alpha, \beta), \quad (2)$$

where $c = (c_{++}, c_{+-}, c_{-+}, c_{--})$ is a real vector, has the same deviation-compensation property. However, we found in [1], [2] that it was not the case. Depending on the choice of the vector of coefficients c , the linear combination

$$E_c^{\text{exp}}(\alpha, \beta) =$$

$$c_{++}P_{++}^{\text{exp}}(\alpha, \beta) + c_{+-}P_{+-}^{\text{exp}}(\alpha, \beta) + c_{-+}P_{-+}^{\text{exp}}(\alpha, \beta) + c_{--}P_{--}^{\text{exp}}(\alpha, \beta)$$

can violate predictions of quantum mechanics (because there is no more compensation of deviations exhibited by individual terms).

We do not know the answer to the question in the title of this section. One could not reject the possibility that there can be found purely statistical reasons for the surprising stability of $E^{\text{exp}}(\alpha, \beta)$ to deviations in individual EPR-Bohm probabilities.

We neither exclude the possibility that a source of compensations is in the experimental arrangement of the EPR-Bohm tests. Thus a detailed analysis of the experimental arrangement is required.

One of the most natural explanations is that in the real experiment one does not prepare a singlet state, but something else. We tried to explore such an explanation in [1], [2]. We started with the hypothesis that the experimental state is pure, but *not maximally entangled*. However, we found some linear combinations $E_c^{\text{exp}}(\alpha, \beta)$ which deviate even from the QM-predictions for nonmaximally entangled states.

¹We emphasize that there can be proposed various classical probabilistic models for the EPR-Bohm experiment which are different from the Bell's one. For some of such classical models, Bell's inequality does not hold, see, e.g., [6], [7]. But we do not discuss this problem in this paper.

3 Bell's arguments would imply that both classical and quantum models should be rejected

It is well known that the experimental statistical data, see, e.g., [5] and [3], violates predictions of the classical model proposed by J. Bell to confront quantum mechanics, namely, the Bell's inequality is violated. On the basis of the statistical test given by the Bell's inequality this classical model should be rejected. We completely agree with this result of the experimental research.

However, we found that the same data violates the QM-predictions for some tests $E_c(\alpha, \beta)$. Should one also conclude that the quantum model should be rejected?

If we follow Bell's reasoning then the quantum model should be also rejected:

There is a family of statistical tests $E_c(\alpha, \beta)$. We have the experimental data. Any model which does not pass one of these tests should be rejected. Thus we have no other choice than to reject any model which does not pass another test.

Conclusion: *If we follow Bell's reasoning then both classical and quantum models should be rejected on the basis of the present experimental statistical data.*

4 New experiments

The crucial question is:

Can one perform an experiment that will produce data confirming predictions of QM for all statistical tests $E_c(\alpha, \beta)$ at the same time?

If one succeed in performing such a “super-experiment”, then the Bell's approach to confronting classical and quantum models would be justified.

If it is impossible to perform such a “super-experiment”, then we should seriously question the whole Bell's approach.

In any event one of the definite consequences of our analysis is that the complete experimental data should be available for theoreticians.

References

- [1] G. Adenier, A. Khrennikov, Anomalies in the EPR-Bell experiment. AIP Conf. Proc., 810, Amer. Inst. Phys., Melville, NY, 2006.
- [2] G. Adenier, A. Khrennikov, Is the Fair Sampling Assumption supported by EPR Experiments? <http://www.arxiv.org/abs/quant-ph/0606122>
- [3] G. Weihs, T. Jennewein, C. Simon, H. Weinfurter, and A. Zeilinger, Phys. Rev. Lett., **81**, 23, p. 5039, (1998).
- [4] J. S. Bell, Physics, **1**, 195, (1964).
- [5] A. Aspect, PHD Thesis, N 2674m Orsay (1983).
- [6] A. Yu. Khrennikov, ed., *Quantum Theory: Reconsideration of Foundations* (Växjö Univ. Press, 2002)
- [7] A. Yu. Khrennikov, *Interpretations of Probability*. VSP Int. Sc. Publishers, Utrecht/Tokyo, 1999 (second edition, 2004).